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Radio Constraints on Activity in Young Brown Dwarfs

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ABSTRACT

We report on searches for radio emission from three of the nearest known young brown dwarfs using the Very Large Array. We have obtained sensitive upper limits on 3.6cm emission from 2MASSW J1207334-393254, TWA 5B and SSSPM J1102-3431, all of which are likely members of the ~ 8 -Myr-old TW Hydrae association. We derive constraints on the magnetic field strength and the number density of accelerated electrons, under the assumption that young brown dwarf atmospheres are able to produce gyrosynchrotron emission, as seems to be indicated in older brown dwarfs. For the young brown dwarf TWA 5B, the ratio of its detected X-ray luminosity to the upper limit on radio luminosity places it within the expected range for young stars and older, active stars. Thus, its behavior is anomalous compared to older brown dwarfs, in which radio luminosity is substantially enhanced over the expected relationship. Our observations deepen the conundrum of magnetic activity in brown dwarfs, and suggest that a factor other than age is more important for determining radio emission in cool substellar objects.

Subject headings: stars: activity – stars: coronae – stars: low mass, brown dwarfs
– stars: pre-main-sequence – radio continuum

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1. Introduction

Several lines of evidence point to young brown dwarfs undergoing a T Tauri phase similar to low-mass pre-main sequence stars: near- and mid-infrared excesses consistent with dusty disks (e.g., Natta et al. 2002; Jayawardhana et al. 2003a), broad, asymmetric $H\alpha$ emission associated with accretion (e.g., Jayawardhana et al. 2003b) irregular photometric and spectroscopic variability (Scholz & Eisloffel 2004; Scholz & Jayawardhana 2005), and forbidden emission lines believed to originate in outflows (Fernández & Comerón 2001; Barrado y Navascués & Jayawardhana 2004). The $H\alpha$ activity seen in (non-accreting) young brown dwarfs is comparable to saturated activity levels in field M dwarfs with similar spectral type and rotation rates (Jayawardhana et al. 2002).

The X-ray properties of young brown dwarfs appear to be similar to young low-mass stars at ~ 1 Myr in age, according to a recent report by Preibisch et al. (2005). Another study by Stelzer et al. (2005) suggests that the X-ray emission of brown dwarfs with the same effective temperature have similar L_X/L_{bol} for a range of ages, from young BDs to field objects. Thus young brown dwarfs appear to share similarities in this magnetic activity signature both with objects of the same age but higher mass and with objects of the same temperature but different age.

In T Tauri stars, magnetic activity (radio and X-ray) is enhanced compared to field stars of Gyr ages. The ratio of radio and X-ray luminosities of a heterogeneous mixture of active stars, including T Tauri stars, has a constant level, $L_R \sim L_X/10^{15.5} \text{ Hz}^{-1}$ (Güdel & Benz 1993). Radio emission from wTTs ranges in luminosity from 10^{15} – $10^{18} \text{ erg s}^{-1} \text{ Hz}^{-1}$, and is generally attributed to a nonthermal mechanism (gyrosynchrotron emission by analogy with the Sun and active stars; White et al. 1992). CTTs are not detected in the radio as frequently as WTTS; the few that are show emission consistent with thermal bremsstrahlung from ionized winds (Martin 1996).

For field brown dwarfs of Gyr ages, magnetic activity detections (primarily radio, X-ray, $H\alpha$) are more sporadic, and do not follow the activity ratios of active stars. The underlying physical mechanism giving rise to the quiescent radio emission, at least in one case (Osten et al. 2006), appears to be similar to that seen in active stars – namely, gyrosynchrotron emission from a population of mildly relativistic electrons. This is in line with the X-ray studies that demonstrate a similarity of emission properties and mechanisms.

In this Letter, we investigate whether the radio emission properties seen in T Tauri stars extend to young brown dwarfs, and whether radio emission from brown dwarfs is enhanced in their youth. We focus on the nearby TW Hydrae association, which has several known brown dwarf members. Its age is sufficiently young (~ 8 Myr) that signatures of accretion and

magnetic activity are still observable. Hence, we expect to see analagous radio properties to T Tauri stars with an without disks.

2. Targets

The vast majority of known young brown dwarfs reside in star-forming regions or clusters at distances ≥ 140 pc, making it extremely difficult, if not impossible, to detect their radio emission with current facilities. However, a few young brown dwarfs have been identified recently in stellar associations located much closer to the Sun. Here we focus on three of the four known sub-stellar members of the TW Hydrae association at ~ 50 pc. Given their relative proximity, these objects offer the best chance of constraining radio emisson from young brown dwarfs.

2.1. 2MASSW J1207334-393254

Gizis (2002) identified 2MASSW J1207334-393254 (hereafter 2M1207) as a likely member of the TW Hydrae association, based on its strong $H\alpha$ emission, low surface gravity and space motion. The case for its youth and membership was strengthened by follow up high-resolution optical spectroscopy (Mohanty et al. 2003). Intriguingly, it shows strong emission both in the Hydrogen Balmer series ($H\alpha$ to $H\epsilon$) and in He I (4471, 5876, 6678, and 7065 Å), compared with other young brown dwarfs of similar spectral type. The $H\alpha$ line is also relatively broad (1200 km/s) and asymmetric. These characteristics suggest that 2M1207 is a (weak) accretor or an exceptionally active object. Recently, Scholz et al. (2005a) have found emission line variations on timescales of both several weeks and several hours, and interpret them as evidence of non-steady accretion. There is evidence for a dusty disk around this object, in the form of mid-infrared excess (Jayawardhana et al. 2003a; Sterzik et al. 2004). Forbidden [O I] emission seen in 2M1207 at least in some epochs is normally associated with winds or outflows in T Tauri stars (Mohanty et al. 2005). An X-ray observation by Gizis & Bharat (2004) resulted in an upper limit to the X-ray luminosity of 1.2×10^{26} erg s⁻¹.

2M1207 has a planetary mass companion located 778 mas away (Chauvin et al. 2004). Using the moving cluster method, Mamajek (2005) has recently revised 2M1207’s distance estimate from 70 pc to 53 ± 6 pc. We adopt this revised distance in our calculations. Given the relatively high mass of the newly found companion (20% of the primary), its wide separation, and the fact that brown dwarf disks appear to be very low mass (e.g. Klein et al.

2003), this system may have formed as a binary brown dwarf, rather than the companion forming out of a ‘protoplanetary’ disk. Especially in that case, the companion itself may be chromospherically active and may even have its own wind.

2.2. TWA 5B

TWA 5B is a companion to the M1.5 T Tauri star TWA 5, discovered by Lowrance et al. (1999), at an apparent separation of 2". It was detected by Tsuboi et al. (2003) in X-rays, with an X-ray luminosity of 4×10^{27} erg s⁻¹, assuming a distance of 50 pc. Mamajek (2005) used the moving cluster method to estimate a distance to TWA5 of 44 ± 4 pc, which we adopt.

2.3. SSSPM J1102-3431

This object was identified as a probable sub-stellar member of the TW Hydrae association by Scholz et al. (2005b). Given its apparent proximity to the T Tauri star TW Hya, these authors noted that the two could form a wide binary. Scholz et al. (2005a) presented a high resolution optical spectrum of SSSPM J1102-3431 exhibiting narrow and symmetric emission lines, which suggest that only weak accretion is taking place, if at all. Mamajek (2005) used the moving cluster method to estimate a distance of 43 ± 7 pc to this object.

3. Observations

The Very Large Array ¹ observed three of the four known TW Hya brown dwarfs at 3.6 cm. Table 2 displays the log of the observations. We made use of an archival observation of TWA 5 in A array (from program AC605) which had sufficient spatial resolution to isolate the brown dwarf companion from the T Tauri star, although not enough integration time to be very sensitive. The data were reduced and calibrated using AIPS software (version 31 Dec03). The observations of 2M1207 were collected in A array on 7 different days from 2005 January 11–19 to accumulate the total on-source time. Each dataset was calibrated and imaged separately and no source was detected. Finally, the visibility datasets were combined to facilitate weak point source detection.

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4. Results

No sources were detected at the location of 2M1207 or its planetary mass companion, nor in maps at the positions of SSSPM J1102-3431 or TWA 5B. A preliminary analysis of the dataset on TWA 5B, presented in

We determined the rms variations in the images using natural weighting. We report the 3σ noise estimate in Table 2 as our 99% confidence limit on the 3.6 cm flux densities.

5. Constraints on Coronal Properties

If young brown dwarfs exhibit accretion signatures and coronal activity (X-ray) signatures with characteristics similar to T Tauri stars, does this similarity extend to radio emission as well? The situation is somewhat more complicated, as radio emission from T Tauri stars can be either thermal bremsstrahlung or gyrosynchrotron radiation: classical T Tauri stars tend to show thermal radio emission, whereas weak-lined T Tauri stars generally display nonthermal emission from electrons accelerated in the presence of a magnetic field. André (1987) suggested that stars with disks may also be emitting non-thermal radio radiation, but it gets absorbed by high density stellar winds.

If we assume that a magnetic field accelerates electrons, we can use the analytic models of White et al. (1989) to investigate possible combinations of parameters. For simplicity, we assume there is a global dipole field, and the nonthermal electrons have no radial falloff with distance. We take the index of the power-law distribution of electrons to be $\delta = 3$, in line with inferences from active early- and late-type M stars that suggest such a hard distribution (White et al. 1989; Osten et al. 2006), and constrain the dipole size to be the object’s radius, $\sim 0.5 R_{\odot}$ (Mohanty et al. 2004). With these simplifying assumptions, the free parameters are the base magnetic field strength and total number density of nonthermal electrons above a cut-off energy. Figure 1 displays the locus of points in magnetic field-electron density space compatible with our upper limit at 3.6 cm. If young brown dwarfs harbor kilogauss magnetic fields, as Scholz & Jayawardhana (2006) suggests, then this constrains the total number density of accelerated electrons to be less than $n_{\text{tot}} \sim 10^5 \text{cm}^{-3}$ or so.

6. Discussion

Claussen & Wilner (2001) investigated centimeter-wavelength radio emission from T Tauri stars in the TW Hydrae association, detecting 5 out of 11 with luminosities in the

range of $5.6\text{--}320\times 10^{14}$ erg s $^{-1}$ Hz $^{-1}$, assuming a distance of 50 pc. The radio spectrum of TW Hya is consistent with partially optically thick thermal free-free emission. The upper limits on TWA brown dwarf radio luminosities in Table 2 are factors of 3–300 times less than those detected for the T Tauri stars at similar distances.

The steady luminosities of field brown dwarfs and very low mass stars detected at radio wavelengths, with the same spectral types as the young BD discussed here, span $\sim 4\times 10^{12}\text{--}3\times 10^{13}$ erg s $^{-1}$ Hz $^{-1}$ (Berger et al. 2001; Osten et al. 2006). Our upper limits suggest that enhancements of radio emission by more than a factor of 3–25 do not occur in these young brown dwarfs compared with field brown dwarfs. This assumes that the underlying emission mechanism is the same, and that age is the primary controller of radio emission. Studies of slower rotating, young T Tauri stars (Mamajek et al. 1999) suggest that rotation may be a more important factor than age in producing detectable radio emission. This suggestion is bolstered by Berger (2002), who pointed out that field brown dwarfs exhibiting radio emission were systematically faster rotators than undetected objects. Two of the three objects investigated here have relatively low $v\sin i$, ≤ 26 km s $^{-1}$, whereas four of the six field low-mass stars/brown dwarfs discussed in Berger (2002) and Burgasser & Putman (2005) have $v\sin i \geq 25$ km s $^{-1}$. This result is only suggestive; a larger sample is needed for confirmation.

The detection of X-ray emission from TWA 5B is indicative, at least in this object, of an enhancement of magnetic activity with youth. Its X-ray luminosity of 4×10^{27} erg s $^{-1}$ (Tsuboi et al. 2003) is a factor of 20–200 times larger than that of field low mass stars of similar spectral type (LHS 2065 and VB 10, Schmitt & Liefke 2002; Fleming et al. 2003, respectively). We would expect, by analogy with T Tauri stars, that there should be radio emission from TWA 5B associated with magnetic activity, and if the $L_X\text{--}L_R$ relation holds for TWA 5B as well, we would expect $L_R \sim 1.2\times 10^{12}$ erg s $^{-1}$ Hz $^{-1}$. This is about two orders of magnitude below our 3σ upper limit, so we cannot rule out the possibility that plasma heating and particle acceleration are occurring in the same ratio in TWA 5B as for active stars. However, the ratio of radio to X-ray luminosities in field brown dwarfs and very low mass stars diverges from that seen in active stars (Berger et al. 2001; Berger 2002), but it is in the opposite sense as seen here: the radio emission exceeds the $L_X\text{--}L_R$ relation by more than four orders of magnitude. If TWA 5B were to behave like the field brown dwarfs detected at radio wavelengths, we would expect its radio emission to be 1.2×10^{16} erg s $^{-1}$ Hz $^{-1}$, or more than two orders of magnitude higher than our upper limit. Thus it appears that radio emission from young brown dwarfs displays a disconnect with the behavior demonstrated by field brown dwarfs of Gyr age.

Another phenomenon seen in pre-main sequence stars, very low mass stars and brown

dwarfs is variability, interpreted as magnetic reconnection flares when varying radio, X-ray, and UV emissions are seen (Berger et al. 2001; Schmitt & Liefke 2002; Hawley & Johns-Krull 2003). Particularly in X-rays, flaring signatures are seen in the absence of evidence of steady emission (Rutledge et al. 2000). Our long observation of 2M1207 encompassed 8.4 hours; if we assume that a typical flare time scale is ~ 30 minutes, then our lack of radio detection implies a flare duty cycle less than 6%, which is still consistent with flare duty cycles from radio detected field brown dwarfs (Osten et al. 2006).

7. Conclusions

This study presents the first attempt to extend studies of activity in young brown dwarfs to radio wavelengths. The results suggest that the anomalous behavior of the radio emission in field brown dwarfs is not primarily a function of age, and may depend on another parameter; rotation has been suggested as a key on two different fronts to controlling the radio emission properties of both young stars and field brown dwarfs. For the near future, further radio studies are limited to the nearest young groups due to sensitivity constraints. The *Expanded VLA* will be instrumental in carrying out these observations, with improvements of up to a factor of 5 for $\nu \leq 10$ GHz, which will allow similar luminosity constraints on clusters up to ~ 100 pc, probing a wider array of star/brown dwarf formation characteristics. Larger samples are needed to explore the dependence of radio emission-induced magnetic activity on temperature, mass, and age in the sub-stellar regime.

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REFERENCES

- André, P. 1987, in *Protostars and Molecular Clouds*, 143–
- Barrado y Navascués, D. & Jayawardhana, R. 2004, *ApJ*, 615, 840
- Berger, E. 2002, *ApJ*, 572, 503

- Berger, E., Ball, S., Becker, K. M., Clarke, M., Frail, D. A., Fukuda, T. A., Hoffman, I. M., Mellon, R., Momjian, E., Murphy, N. W., Teng, S. H., Woodruff, T., Zauderer, B. A., & Zavala, R. T. 2001, *Nature*, 410, 338
- Burgasser, A. J. & Putman, M. E. 2005, *ApJ*, 626, 486
- Chauvin, G., Lagrange, A.-M., Dumas, C., Zuckerman, B., Mouillet, D., Song, I., Beuzit, J.-L., & Lowrance, P. 2004, *A&A*, 425, L29
- Claussen, M. J. & Wilner, D. J. 2001, *Bulletin of the American Astronomical Society*, 33, 1435
- Fernández, M. & Comerón, F. 2001, *A&A*, 380, 264
- Fleming, T. A., Giampapa, M. S., & Garza, D. 2003, *ApJ*, 594, 982
- Gizis, J. E. 2002, *ApJ*, 575, 484
- Gizis, J. E. & Bharat, R. 2004, *ApJ*, 608, L113
- Güdel, M. & Benz, A. O. 1993, *ApJ*, 405, L63
- Hawley, S. L. & Johns-Krull, C. M. 2003, *ApJ*, 588, L109
- Jayawardhana, R., Ardila, D. R., Stelzer, B., & Haisch, K. E. 2003a, *AJ*, 126, 1515
- Jayawardhana, R., Mohanty, S., & Basri, G. 2002, *ApJ*, 578, L141
- . 2003b, *ApJ*, 592, 282
- Klein, R., Apai, D., Pascucci, I., Henning, T., & Waters, L. B. F. M. 2003, *ApJ*, 593, L57
- Lowrance, P. J., McCarthy, C., Becklin, E. E., Zuckerman, B., Schneider, G., Webb, R. A., Hines, D. C., Kirkpatrick, J. D., Koerner, D. W., Low, F., Meier, R., Rieke, M., Smith, B. A., Terrile, R. J., & Thompson, R. I. 1999, *ApJ*, 512, L69
- Mamajek, E. E. 2005, *ApJ*, 634, 1385
- Mamajek, E. E., Lawson, W. A., & Feigelson, E. D. 1999, *Publications of the Astronomical Society of Australia*, 16, 257
- Martin, S. C. 1996, *ApJ*, 473, 1051
- Mohanty, S., Jayawardhana, R., & Barrado y Navascués, D. 2003, *ApJ*, 593, L109

- Mohanty, S., Jayawardhana, R., & Basri, G. 2004, *ApJ*, 609, 885
- . 2005, *ApJ*, 626, 498
- Natta, A., Testi, L., Comerón, F., Oliva, E., D’Antona, F., Baffa, C., Comoretto, G., & Gennari, S. 2002, *A&A*, 393, 597
- Osten, R. A., Hawley, S. L., Bastian, T. S., & Reid, I. N. 2006, *ApJ*, 637, 518
- Preibisch, T., McCaughrean, M. J., Grosso, N., Feigelson, E. D., Flaccomio, E., Getman, K., Hillenbrand, L. A., Meeus, G., Micela, G., Sciortino, S., & Stelzer, B. 2005, *ApJS*, 160, 582
- Rutledge, R. E., Basri, G., Martín, E. L., & Bildsten, L. 2000, *ApJ*, 538, L141
- Schmitt, J. H. M. M. & Liefke, C. 2002, *A&A*, 382, L9
- Scholz, A. & Jayawardhana, R. 2006, *ApJ*, in press
- Scholz, A., Jayawardhana, R., & Brandeker, A. 2005a, *ApJ*, 629, L41
- Scholz, R.-D., McCaughrean, M. J., Zinnecker, H., & Lodieu, N. 2005b, *A&A*, 430, L49
- Stelzer, B., Micela, G., Flaccomio, E., Neuhäuser, R., & Jayawardhana, R. 2005, *ArXiv Astrophysics e-prints*
- Sterzik, M. F., Pascucci, I., Apai, D., van der Blik, N., & Dullemond, C. P. 2004, *A&A*, 427, 245
- Tsuboi, Y., Maeda, Y., Feigelson, E. D., Garmire, G. P., Chartas, G., Mori, K., & Pravdo, S. H. 2003, *ApJ*, 587, L51
- White, S. M., Kundu, M. R., & Jackson, P. D. 1989, *A&A*, 225, 112
- White, S. M., Pallavicini, R., & Kundu, M. R. 1992, *A&A*, 259, 149

Table 1. TW HYa Brown Dwarf Properties

Source	sp. type	distance ^a (pc)	vsini (km s ⁻¹)	L _X (10 ²⁷ erg s ⁻¹)	H α 10% width (km s ⁻¹)	Refs ^b
2M1207	M8.0	53 \pm 3	13.0	<0.12	200–300	MJBN03,GB04,SJB05
TWA 5B	M8.5	44 \pm 4	26.0	4	160	MJBN03,T03,MJB05
SSSPM 1102	M8.5	43 \pm 7	—	—	190	SJB05

^aDistances taken from Mamajek (2005).

^bMJBN03=Mohanty et al. (2003), GB04=Gizis & Bharat (2004),SJB05=Scholz et al. (2005a), T03=Tsuboi et al. (2003),MJB05=Mohanty et al. (2005)

Table 2. Table of Observations, Radio Properties

Source	Obsn Dates	TOS (s)	array config.	F _R (μ Jy)	L _R (10 ¹⁴ erg s ⁻¹ Hz ⁻¹)
2M1207	2005/01/11–19	30292	BnA	<29	<0.98
TWA 5B	2002/02/20 ^a	850	A	<120	<2.8
	2005/06/09	6150	CnB	<84	<2.0
SSSPM1102	2005/10/29	12350	DnC	<42	<1.6

^aArchival observation from project AC605

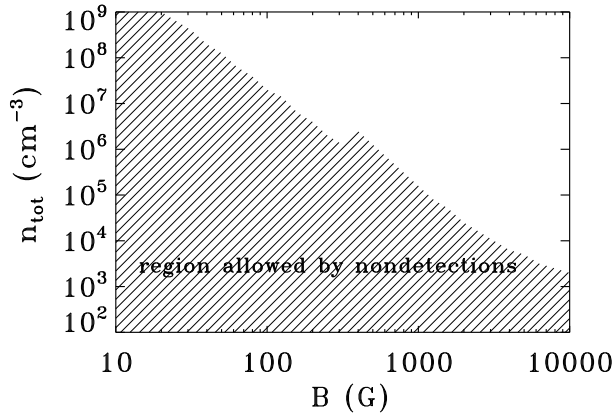


Fig. 1.— Region of space constrained by the nondetection of radio flux from 2M1207. We assume that the emission mechanism is gyrosynchrotron, from a relatively hard population of nonthermal electrons within a dipole magnetic field configuration, and allow the electron density to have no radial dependence (i.e. constant with radius). The shaded section indicates locations consistent with the 3σ upper limit of $29\mu\text{Jy}$ on 2M1207 at a distance of 53 pc.